

## **Thermal Conductivity of the Ternary Refrigerant Mixtures (R32-R125-R134a)**

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**ABSTRACT**

The thermal conductivity of the ternary mixture of difluoromethane (R32), pentafluoroethane (R125) and 1,1,1,2-tetrafluoroethane (R134a) has been studied. The relative steady-state method of the co-axial cylinders was used. The total systematic error of these measurements was 3% with the confidence probability of 0.95. The experimental data were obtained in the liquid and gas phases along the isobar and/or isotherm lines in the temperature range of 290 to 400 K at pressures up to 15.0 MPa. The polynomial expression was used to describe the data obtained, the standard deviation being less than 1.1%. The comparison between different data is presented and discussed.

**KEY WORDS:** density; equation of state; experimental method; gas phase; liquid phase; phase equilibrium; refrigerant.

## 1. INTRODUCTION

The most recent activity of the authors involves experimental study of the thermal conductivity of five refrigerants (R134a, R152a, R125, R32, R218) and four binary mixtures (R134a-R152a, R32-R125, R32-R134a and R152a-R218). The results obtained were published in [1,2,3]. The present study focuses on the ternary mixture of difluoromethane (R32), pentafluoroethane (R125) and 1,1,1,2-tetrafluoroethane (R134a) and would help address the existing lack of data on the multi-component compositions alternative to ozone depleting substances used in refrigeration industry.

## 2. EXPERIMENTAL METHOD

The steady-state co-axial cylinder method for measuring the thermal conductivity ( $\lambda$ ) of the target refrigerant samples was implemented. The apparatus operated in a relative mode was described in detail in our previous publication [4].

The latest modifications were made to improve the control and measurement devices. The experimental cell consists of two co-centre cylinders of about 300 mm length, separated by a gap of 0.17 mm. The calorimetric heater of 4 W is placed inside the smaller cylinder of about 11.7 mm in diameter. The temperature difference between cylinders is measured with six-junction differential thermocouple. Pressure is measured with a standard Bourdon tube gauge with accuracy of 0.4%. The cell is placed in a massive copper thermostat with four-sectional heater to provide isothermal conditions along the cell. The temperature variation while measuring does not exceed 0.01 K. We estimate the uncertainty of thermal conductivity measurements to be 3.5% with the confidence probability of 0.95.

Standard samples of helium, argon and xenon were used for the gas calibration, and liquid carbon dioxide and toluene were used for the liquid calibration in order to determine the device constants in the specified temperature range. The standard deviation of the results of 68 measurements within gas calibration series from the reference data was 0.9%, and the same for 33 measurements within liquid calibration series was 1.1%. The samples of refrigerant ternary solution were prepared in the laboratory by weighing. The composition of each solution is determined with a standard error of about 0.001 weight fraction. The mass fractions of the components were as follows: 0.204 (R32), 0.397 (R125), and 0.399 (R134a).

### **3. RESULTS**

Thermal conductivity values were determined along isotherms and isobars in the temperature range of 290 to 400 K in the liquid and gas phases. In the liquid phase, the pressure was varying from the saturation pressure to 15.0 MPa. In the gas phase, the pressure was varying from 0.29 MPa to that close to the phase equilibrium curve. The results are presented in Table I, II.

In order to check if there is any effect of natural convection inside the heat-conducting gap, the measurements were performed in a way that every value were measured at two different temperature drops between the cylinders. These tests did not confirm any noticeable presence of convection.

We used a simple polynomial to correlate the data obtained both in liquid and gas phases. The values of thermal conductivity of the investigated mixture were described by the expression:

$$\lambda \cdot 10^4 = \sum_{i=0}^2 \sum_{j=0}^2 a_{ij} \cdot P^i T^j, \quad (1)$$

where thermal conductivity  $\lambda$  is shown in  $\text{W m}^{-1} \cdot \text{K}^{-1}$ , pressure  $P$  – in MPa, and temperature  $T$  – in K. The polynomial constants of the above expression are as follows:

- For the gas phase:  $a_{00}=91.61192$ ;  $a_{01}=-0.40779$ ;  $a_{02}=1.811 \cdot 10^{-3}$ ;  $a_{10}=81.75491$ ;  
 $a_{11}=-0.22038$ ;  $a_{20}=3.630$
- For the liquid phase:  $a_{00}=3321.11914$ ;  $a_{01}=-11.57446$ ;  $a_{02}=9.732 \cdot 10^{-3}$ ;  
 $a_{10}=-17.86486$ ;  $a_{11}=0.10087$ ;  $a_{20}=-0.26599$
- For both phases:  $a_{12}=a_{21}=a_{22}=0$

The standard deviation between the results of calculation by Eq. (1) and experimental data is 1.05%.

#### 4. DISCUSSION AND CONCLUSION

We are aware of the only published work [5] where the thermal conductivity data on the ternary mixture of the specified refrigerants are presented. The results of that study were obtained by the hot-wire technique for several mixture compositions. Analysis of these data shows a certain disagreement with our results. The values presented in study [5] are lower than our data. This difference increases as temperature rises, e.g. at room temperature it is lower than 3% while at 400K it exceeds 10%. Such difference indicates that our data obtained at the heat-conducting clearance of 0.17 mm, which is covariant to the effective length of the infrared radiation photon free path. Therefore, our data reflect the molecular mechanism of conductivity rather than the data [5].

## REFERENCES

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Table I. Experimental Data on Thermal Conductivity in Gas Phase,  $\lambda$  ( $\text{W m}^{-1}\cdot\text{K}^{-1}$ )

$T$	$P$	$\lambda$	$T$	$P$	$\lambda$	$T$	$P$	$\lambda$
(K)	(MPa)		(K)	(MPa)		(K)	(MPa)	
288.2	.2	129	341.9	.59	169	387	2.06	215
289.5	.2	131	342.7	.59	170	378.6	2.06	216
294.7	.29	135	357.5	.59	181	346.1	2.06	191
295.9	.29	136	358.3	.59	182	346.7	2.06	192
330.4	.29	158	373	.59	194	359.5	2.06	198
331.3	.29	159	373.7	.59	194	360.2	2.06	198
343.8	.29	168	387	.59	203	374.4	2.06	211
344.7	.29	169	387.6	.59	206	375.1	2.06	209
310.9	.29	145	400.1	.59	216	360.3	3.63	243
311.9	.29	146	400.7	.59	216	360.9	3.63	244
358	.29	179	400.1	2.06	224	367.3	3.63	238
358.5	.29	180	400.7	2.06	224	36.8	3.63	237
371.9	.29	191	400.1	1.08	215	308.6	1.08	156
372.6	.29	192	400.7	1.08	216	309.7	1.08	157
385.9	.29	204	315.9	1.08	159	330.3	2.06	187
386.6	.29	202	316.8	1.08	160	331	2.06	187
400.3	.29	211	330.7	1.08	166	335.3	2.06	188

Table I. (*Continued*)

$T$	$P$	$\lambda$	$T$	$P$	$\lambda$	$T$	$P$	$\lambda$
(K)	(MPa)		(K)	(MPa)		(K)	(MPa)	
400.9	.29	213	331.5	1.08	167	336.1	2.06	187
287.2	.29	130	346.2	1.68	177	373.9	3.63	237
289.1	.29	131	346.9	1.08	177	374.5	3.63	238
287.9	.59	136	360.4	1.08	187	379.2	3.63	239
289.5	.59	137	361	1.08	188	379.8	3.63	237
309.6	.59	147	373.8	1.08	199	384.8	3.63	235
310.6	.59	148	374.4	1.08	198	385.3	3.63	236
325.7	.59	157	387	1.08	209	389.5	3.63	238
326.8	.59	158	387.6	1.08	210	390.1	3.63	238
394.8	3.63	243	360.4	3.04	217	377.9	3.04	223
395.4	3.63	242	360.9	3.04	218	382.8	3.04	224
353.7	3.04	222	366.1	3.04	219	383.4	3.64	225
354.3	3.04	223	366.6	1.04	220	388.3	3.04	227
347.3	3.12	225	371.9	3.04	222	388.9	3.04	228
347.9	3.94	221	372.5	3.04	222	400.5	3.04	237
347.1	3.04	222	377.3	3.0	223	401.1	3.04	236
400.5	3.63	241	401	3.63	243			



Table II. Experimental Data on Thermal Conductivity in Liquid Phase,  $\lambda$  ( $\text{W m}^{-1}\cdot\text{K}^{-1}$ )

$T$	$P$	$\lambda$	$T$	$P$	$\lambda$	$T$	$P$	$\lambda$
(K)	(MPa)		(K)	(MPa)		(K)	(MPa)	
296.4	1.27	757	350	15	654	310	1.67	694
296.9	1.27	756	349.8	5	541	310.5	1.67	689
295.4	1.27	765	350.1	5	540	323.5	15	748
296.4	1.27	758	376	15	581	324	15	748
296.2	5	797	376.3	15	582	323.4	10	722
296.9	5	796	376.1	10	515	323.9	10	719
296.7	15	873	376.3	10	517	323.5	5	669
297.2	15	869	387.8	10	477	324	5	667
297.3	10	828	388.2	10	483	336.9	3.53	589
310.1	10	773	388.1	15	555	337.6	3.53	586
310.6	10	769	399.8	15	537	336.9	10	666
310.2	15	816	400	15	535	337.2	10	666
310.6	15	809	399.8	10	448	336.9	5	604
310.1	5	728	400.1	10	445	337.3	5	603
310.6	5	725	362.3	5.49	490	388.2	10	480
297.9	10	824	387.8	15	554	387.9	10	492
310.1	2.06	701	362.6	5.49	489	350.1	10	621

Table II. *(Continued)*

$T$	$P$	$\lambda$	$T$	$P$	$\lambda$	$T$	$P$	$\lambda$
(K)	(MPa)		(K)	(MPa)		(K)	(MPa)	
310.5	2.06	698	387.9	10	479	350.2	10	620
324	3.04	636	336.2	15	712	375.8	6.47	461
324.3	3.04	638	361.6	6.96	515	376.1	6.47	464
335.8	15	712	361.9	6.96	516	399.7	10	447
350.3	4.02	526	349.7	15	651	350.1	4.02	526
400.1	10	442						